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FRACTAL ANALYSIS TOOLS FOR CHARACTERIZING THE COLORIMETRIC ORGANIZATION OF DIGITAL IMAGES

Case Study using Natural and Synthetic Images

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Abstract: The colorimetric organization of RGB color images is analyzed through the computation of algorithms which can characterize fractal organizations in the support and population of their three-dimensional color histogram. These algorithms have shown that complex organizations across scales exist in the colorimetric domain for natural images with often non-integer fractal dimension over a certain range of scale. In this paper, we apply this method of colorimetric characterization to synthetic images produced by rendering techniques of increasing sophistication. We show that the fractal or scale invariant signatures are more pronounced when the realism of the synthetic images increases. Such results could have interesting applications to improve the colorimetric realism of synthetic images. This also may contribute to progress in classification and vision, in using fractal colorimetric properties to differentiate natural and synthetic images.

1 INTRODUCTION

Fractal theory provides useful tools to analyze properties and regularities across scales in images. Fractal structures are well-established in the spatial organization of static natural images (Mandelbrot, 1983; Burton and Moorhead, 1987; Schroeder, 1991; Ruderman and Bialek, 1994; Gouyet, 1996; Olshausen and Field, 2000; Hsiao and Millane, 2005) and in the temporal organization of moving images (Dong and Atick, 1995). Here, we investigate a third domain: the fractal structures in the colorimetric organization of digital images. This distinct aspect of color images has only been considered very recently under the scope of fractal theory and it has been established (Chauveau et al., 2008; Chapeau-Blondeau et al., 2009; Chauveau et al., 2009) that natural color images can also exhibit a nontrivial self-similar, scale invariant, fractal organization in the colorimetric domain. Possible origins for this fractal organization of the colors in natural images are under current investigation. A possible hypothesis would be that this fractal behavior in the colorimetric domain would be related to the properties of the natural scenes, which can contain many different structures and objects of various sizes and colors, appearing at various depths, various angles, under various lighting and shading conditions. These combined ingredients could lead to the existence in typical natural scenes, of many colors with each color affected by many modulating factors, these together building up a fractal organization for the colors. In this report, we propose to verify this hypothesis by applying a fractal analysis to synthetic color images produced by rendering algorithms of increasing sophistication. We analyse the colorimetric organization across scales demonstrated by these synthetic images, and compare them with the typical fractal behavior of natural images.

2 FRACTAL ANALYSIS OF RGB HISTOGRAMS

We consider RGB color images with N_{pix} pixels. The three-dimensional color histogram of the color images is a cloud of points P_n, $n \in [1,\dots,N_{pix}]$ distributed over the Q^3 cells of the colorimetric cube $[0,Q-1]^3$ with Q the dynamic of each of the three (R,G,B) components. For illustration, Figs. 1 and 2 provide two examples of natural color images with their three-dimensional color histogram in the RGB

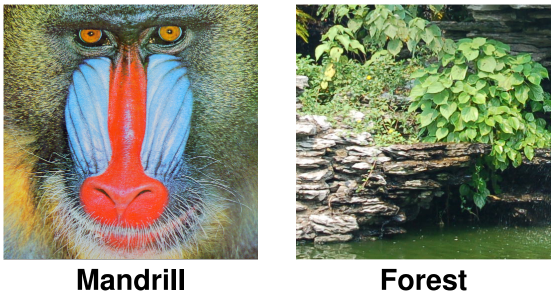

Figure 1: Two natural color RGB images with size 512×512 pixels and $Q = 256$ levels.

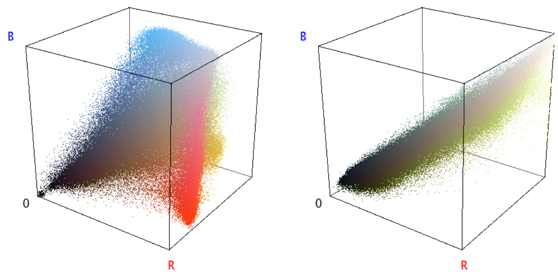

Figure 2: Three-dimensional color histogram in the RGB colorimetric cube $[0,255]^3$ for the images of Fig. 1.

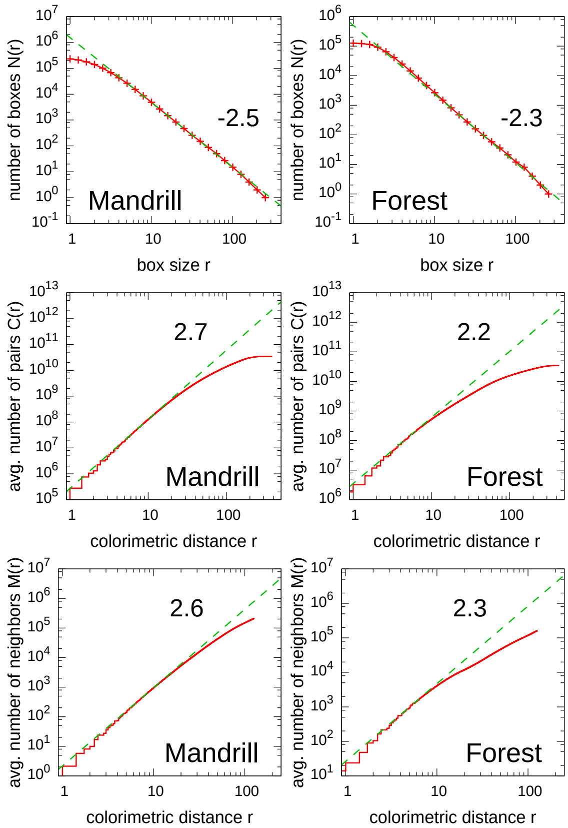

Figure 3: Scale analysis of the color histograms of Fig. 2. *From top to bottom*: number $N(r)$ of covering boxes with size r to cover the color histogram, average number of pairs $C(r)$ within the colorimetric distance r, and average number of neighbors $M(r)$ inside the sphere of radius r. The number is the slope of the dashed line manually adjusted to fit the measures (solid line) over the largest possible scale range.

colorimetric cube. In order to characterize the organization of the three-dimensional color histograms of images, it has recently been proposed in (Chauveau et al., 2008; Chapeau-Blondeau et al., 2009; Chauveau et al., 2009) to apply fractal analysis tools. These tools consist of three distinct measures on the three-dimensional color histogram in the RGB colorimetric cube, as a function of the colorimetric distance r, which has so been considered as a scale parameter. As visible in Fig. 3, a fractal signature is observable in the log-log plots of the three measures $N(r)$, $C(r)$ and $M(r)$ when applied to natural color images. In the following, to investigate possible origins of the fractal properties observed in the colorimetric domain of natural images, we propose to apply these fractal analysis tools to synthetic images and analyze their behaviors.

3 RENDERING TECHNIQUES

3.1 Synthetic Images more Sophisticated

We now perform an image synthesis process, with several rendering techniques of increasing sophistication, implemented in succession, in order to insert more and more realism in the synthesized color images. We choose first to work with synthetic images based on variations of a simple virtual object like the classical Utah teapot. Fig. 4 presents the first and the last of four synthetic images (from image A to D) realized with such a synthesis process. Fig. 5 presents their respective RGB histograms. Image A is composed of thirteen teapots of various solid colors above a white background. In image B, two specular lights have been added. In image C, a gray texture has been applied to the teapots. And in image D, a gray background image has been added behind the teapots. The log-log plots of the three measures $N(r)$, $C(r)$ and $M(r)$ are presented in Fig. 6. By comparison with the behavior observed in Fig. 3 for natural images, we globally observe for the synthetic images of Fig. 4 straight lines over a smaller range of scale r. With the "box-counting" measure, we observe that the slope of the line is increasing together with the sophistication of the generated images. This is caused by the increase of the number of colors used in the images and the diffusion of the colors in the RGB colorimetric

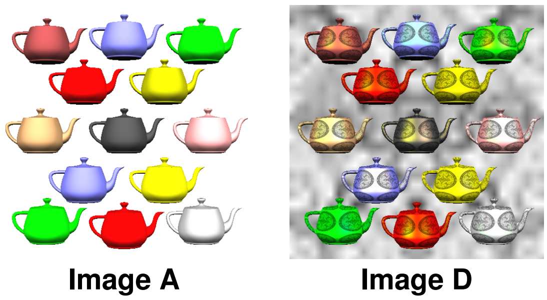

Figure 4: The first and the last of four synthetic color RGB images with size 512×512 pixels and $Q = 256$ levels, constructed in a more and more sophisticated way using various solid colors, specular lights and textures.

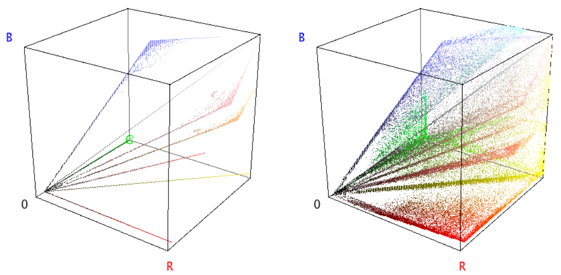

Figure 5: Three-dimensional color histogram in the RGB colorimetric cube $[0,255]^3$ for the images of Fig. 4.

cube. With the "pair-correlation" measure, we observe in images A to C a slope less than 1, caused by the presence of the white background that creates a very large population of white pixels with the same (R,G,B) components. In image D, the white background has been replaced by a gray image which adds a large number of gray colors, located on a straight line in the RGB colorimetric cube. This is why the image has a slope close to 1, but a little more than 1 because of the other colors present in the image. With the "correlation integral" measure, we observe a stronger fractal signature over larger scales as a result of the sophistication of the generated images.

3.2 Towards a Stronger Fractal Signature

When the specular lights and the textures are successively added, we observe in Fig. 3 that the three-dimensional color histograms become more diffuse and contain an increasing number of different colors. Therefore, lights and textures used in the synthetic images play an important part in the complexity of the three-dimensional RGB color histograms. We propose to enhance the realism of the synthetic images by using advanced rendering techniques like shadows, reflection, and bump mapping, as we real-

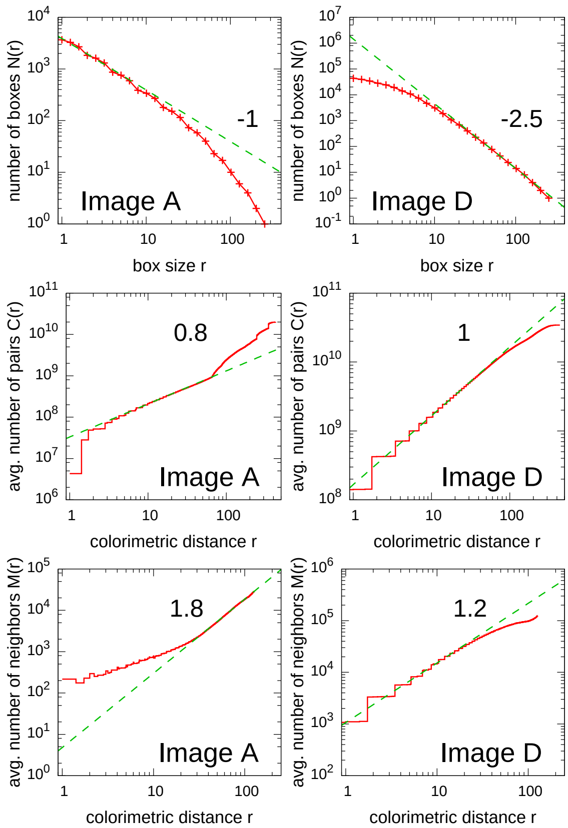

Figure 6: Same as Fig. 3 for the color histograms of Fig. 5.

Figure 7: Two RGB color highly sophisticated synthetic images with size 512×512 pixels and $Q = 256$ levels.

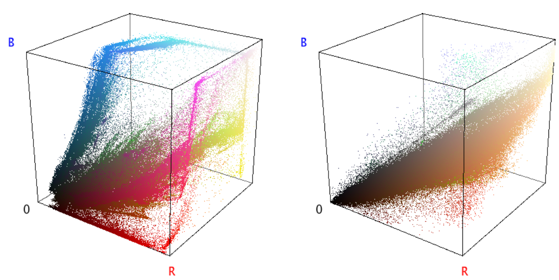

Figure 8: Three-dimensional color histogram in the RGB colorimetric cube $[0,255]^3$ for the images of Fig. 7.

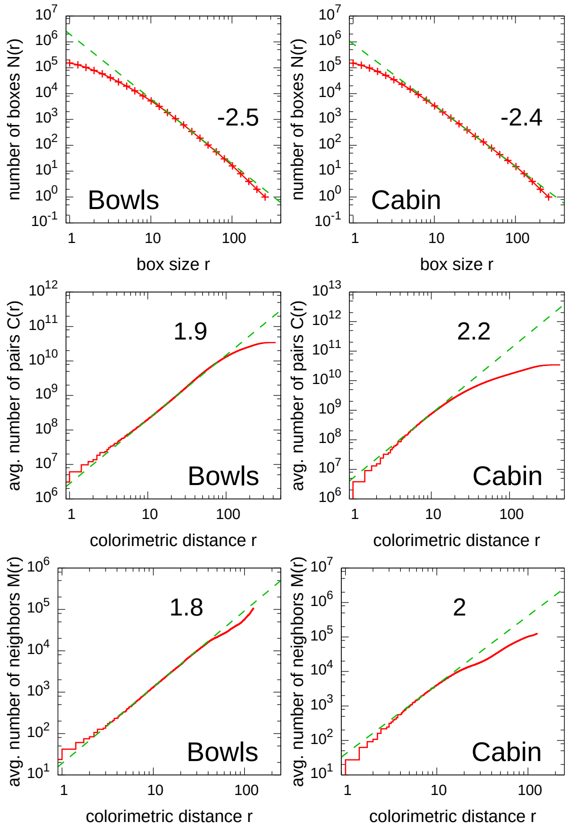

Figure 9: Same as Fig. 3 for the color histograms of Fig. 8.

ize in the images of Fig. 7. When using such techniques, the three-dimensional color histograms gain a stronger fractal signature, which are manifested in Fig. 9 by the plots of $N(r)$, $C(r)$ and $M(r)$ with lines of non-integer slopes. Such fractal organizations are close to those found in natural images (see Fig. 3).

4 CONCLUSIONS

Recent studies have demonstrated that natural images could display fractal structure in their colorimetric organization. To further understand the possible origins for this fractal behavior, we have analyzed the colorimetric organization of synthetic images with the same fractal tools used in (Chauveau et al., 2008; Chapeau-Blondeau et al., 2009; Chauveau et al., 2009). From a very poor synthetic image in the colorimetric domain we have applied standard rendering techniques to increase the richness of the corresponding three-dimensional color histograms. It appears that these simple rendering techniques are able to increase the complexity of the color histogram up to the point where the three tested fractal tools demonstrate a fractal signature more pronounced as the sophistication of the rendering techniques increases. It is to be noted that these results are obtained with a scene which is very simple and presents no fractal properties in the spatial domain.

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